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ON THE DETECTION OF MAGNETOSPHERIC RADIO BURSTS FROM URANUS AND NEPTUNE

C. F. Kennel[1] and J. E. Maggs[2]

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Physics Department
University of California
Los Angeles, California 90024

[1]Department of Physics and Institute of Geophysics and Planetary Physics
University of California
Los Angeles, California 90024

[2]Institure of Geophysics and Planetary Physics
University of California
Los Angeles, California 90024

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Earth, Jupiter, and Saturn are sources of intense but sporadic bursts of electromagnetic radiation which we call Magnetospheric Radio Bursts (MRB). Kaiser and Stone[(1)] ncted that the striking similarity of the differential power flux spectra of the MRB from all three planets suggested a common generation mechanism. In this note we scale the intensity of MRB for the solar wind power input into a planetary magnetosphere and explore the consequences for possible detection of MRB from Uranus and Neptune.

Earth's magnetospheric radio bursts (EMRB) are observed at kilometric wavelengths, with a power flux spectral peak near 200 - 300 kHz, a bandwidth roughly half the peak frequency, and a high frequency cutoff near but below the electron gyrofrequency corresponding to the polar surface magnetic field. Earth's MRB last a few minutes. Jupiter's MRB (JMRB) occur at decametric wavelengths, with a power flux spectral peak near 7 - 8 MHz, a bandwidth again roughly half the peak frequency, and a high frequency cutoff below the polar surface electron gyrofrequency. Jupiter's MRB also last a few minutes. Saturn's MRB are observed at hectometric wavelengths, with a power flux spectral peak near 1 MHz and a bandwidth of roughly half the peak frequency, and again last a few minutes. The similarities in the power flux spectra together with the burst occurrence patterns suggest a common physical origin for all three MRB.

Gurnett[2] has shown that EMRB are associated with the brightening of auroral arcs in the evening sector of the auroral zones, and are radiated over a large solid angle. Assuming EMRB are radiated isotropically over a hemisphere, Gurnett has estimated that the total EMRB power radiated can be as large as 10^9 W. Brown[3] and Desch and Carr[4] have shown that the peak power flux of JMRB at earth can be as high as 2×10^{-19} W/m^2 Hz. Assuming a 4 MHz bandwidth, and like Gurnett, that the power is radiated isotropically over a hemisphere, the total JMRB power radiated can be as large as 2×10^{12} W. Brown[5] has measured an SMRB peak power flux at earth in excess of 5×10^{-20} W/m^2 Hz. Assuming a 500 kHz bandwidth and isotropic hemispherical radiation implies that the total SMRB power can be as large as 2×10^{11} W.

The most striking difference between EMRB and JMRB is the modulation of Jupiter's decametric radiation by its moon, Io. The frequency of occurrence of JMRB is strongly dependent on the phase angle of Io at high frequencies near the cutoff where the power flux is low, but at low frequencies near the peak in the power flux, emission occurs at all Io phase angles with Io producing modulations in the frequency of occurrence at 10 MHz of only about a factor of 2 (Dulk and Clark[6]). This suggests that (1) either Io is not the sole source of low frequency JMRB, or (2) that if Io is the low frequency source, the radiation is much less strongly beamed than at higher frequencies. If the low frequency noise is not beamed, our above hemispherical estimate of the source power seems reasonable. It is several orders of magnitude larger than Warwick's[7] estimates based

on the beamed power fluxes observed at higher frequencies. Since SMRB have only recently been detected, there has not been time to search for modulations due to any of Saturn's satellites.

While the plasma physical mechanism responsible for EMRB has not been isolated (but see Palmadesso et al.[8]), we feel that Gurnett's identification of EMRB with auroral arc brightenings makes sense theoretically, since earth's auroral arcs are known to involve strong magnetic field-aligned currents (FAC); currents which are carried by field-aligned beams of electrons with 5 - 10 keV typical peak energies. Since the auroral electron beams are one of the most strongly nonthermal electron distributions observed in the earth's magnetosphere, they are good candidates for producing strongly nonthermal EMRB. The kilometric noise may well be associated with the anomalous resistance process responsible for the formation of the auroral electron beams in the first place.

Vasyliunas[9] and Kennel[10] have argued that FAC are a necessary feature of any hydromagnetic interaction of an exterior flow with a compact central body. Field-aligned currents are necessary to transmit stresses between the magnetosphere and ionosphere. For the earth, the FAC are driven by the interaction of the solar wind with the magnetosphere and ionosphere-atmosphere. For Jupiter, a generally similar set of FAC driven by the solar wind is also expected (Kennel and Coroniti[11]); Kennel and Coroniti have argued that the FAC connecting to Jupiter's polar cap could be large enough to exceed the threshold for anomalous resistance. Recently, Kivelson and Winge (unpublished work) have presented Pioneer 11 observational evidence for Jovian

FAC on field lines near Ganymede's L shell and just inside the trapping boundary of >15 keV electrons. These observations, if analogy with earth holds true, favor an auroral FAC system. Since the existence of SMRB argues for the existence of a Saturnian magnetosphere, Saturn, too, should have a system of FAC, in broadest outline similar to those of Jupiter and earth, driven by the solar wind.

The interaction of Io with Jupiter's co-rotating plasmasphere is also expected to create a system of FAC which penetrates Jupiter's ionosphere on Io's flux shell. Goldreich and Lynden-Bell(12) and Gurnett(13) have both proposed that these FAC are responsible for Io's portion of Jupiter's MRB. Thus current thinking on the source of JMRB and EMRB converges: they are produced by FAC. However, while it seems clear that earth, Jupiter, and Saturn can have systems of FAC associated with the interaction of their ionospheres-atmospheres with the solar wind, we do not have the same assurance that each and every satellite produces FAC of sufficient intensity to modulate MRBs, since the above theories do not help us to understand why Io modulates Jupiter's MRB and Europa does not.

If MRB's are produced dominantly by a solar wind interaction, their power flux spectra might be expected to scale as the total solar wind power dissipation into the magnetosphere. The frequencies of the emissions seem to scale as the surface magnetic field for earth and Jupiter. The solar wind power dissipation can be estimated from the work done by the magnetopause currents at the nose of the magnetosphere in the motional

EMF of the solar wind. Using standard solar theory to define solar wind parameters, Kennel[14] estimated that the power dissipation $\dot{W}_p$ into a given planetary magnetosphere scales to that at earth $\dot{W}_E$ as

$$\dot{W}_p/\dot{W}_E = \left(M_p/M_E\right)^{2/3} r^{-4/3} = \left(R/R_E\right)^2 \left(B_p/B_E\right)^{2/3} r^{-4/3}$$

where $M = B_p R^3$ is the magnetic dipole moment, B_p is the surface magnetic field, R the planet's radius, and r its heliocentric distance in AU.

Kaiser and Stone[1] point out that Jupiter's observed polar field strength can be correctly predicted from the observed properties of EMRB and JMRB by assuming that the maximum (cutoff) frequencies of MRB are the surface electron gyrofrequencies and that the maximum and peak frequencies of MRB scale linearly with B_p. Using the observed properties of SMRB and the same assumptions they estimate a polar field strength of 2 Gauss for Saturn. Saturn's estimated field strength also agrees within a factor 2 of the "magnetic Bode's law" estimate, which assumes that a planet's dipole moment M scales as its rotational angular momentum L. While there is little theoretical justification for the magnetic Bode's law, Hill and Michel[15] have pointed out that it is surprisingly well obeyed by the objects in the solar system, in the sense that the spread in M/L is much less than the spread in L.

Using measured values of B_E and B_J and the Bode's law estimate for B_S, we plot in figure 1 the power flux spectra of JMRB

and SMRB measured by Brown[3,5] and a spectrum of EMRB measured by Gurnett[2]; the power flux density is normalized to the solar wind power dissipation rate, and the frequency is normalized to the surface electron cyclotron frequency. We chose $\dot{W}_E = 5 \times 10^{11}$ W, corresponding to highly disturbed times, when intense bursts should be most likely. Although the JMRB and SMRB data were collected from the same experiment, they are presented in different ways. The JMRB spectrum is a composite of many events made up of the average of the peak intensity of the most intense bursts. The SMRB and EMRB spectra are from single, very intense, events on 16 Dec. 71 and 20 Dec. 73, respectively. The bandwidth of the JMRB composite spectrum can be expected to be larger than a single JMRB spectrum because the peak in the power flux does not always occur at the same frequency. We note that the solar wind was strong on 20 Dec. 73, a magnetically disturbed day with $\Sigma k_p = 32+$. A strong solar wind disturbance passed over earth on 11 Nov. 71 with $\Sigma k_p = 24-$; for a nominal solar wind speed, this disturbance would arrive at Saturn on 16 Dec. 71, the day of the SMRB event. It is not possible to determine the properties of the solar wind for the JMRB spectrum, because it is a composite of many events.

The close similarity of the JMRB and SMRB normalized spectra, and the similar, but lower EMRB normalized spectra, suggest that the scaling of MRB power to the solar wind-magnetosphere dissipation power is a reasonable hypothesis. It appears, however, that Jupiter and Saturn might radiate 1 - 5% of the solar wind energy, whereas earth might be less efficient. We obtain

high efficiencies for MRB radiation because we have scaled to the most intense fluxes observed in bursts of short duration, but for the purpose of investigating the detectability of MRB, we clearly should consider the most intense events.

In view of the apparently greater efficiency of Jupiter and Saturn for producing MRB, we have considered the alternate hypothesis, that Io-like interactions are responsible. We scaled the theories of Gurnett and of Goldreich and Lynden-Bell to the satellites of Saturn, assuming that perhaps one of Saturn's satellites might share Io's peculiarities. In view of the existing theoretical uncertainties and lack of accurate knowledge of many physical parameters entering into these theories, we do not feel that our results are quantitatively reliable. However, our most optimistic estimates indicated that no moon of Saturn could produce the SMRB unless its efficiency exceeded Io's by more than a factor of 5.

We now combine the tentative scaling laws to speculate on the detectability of MRB from Uranus and Neptune. We assume that the peak power in MRB scales as the solar wind magnetospheric energy dissipation and that Uranus' and Neptune's dipole moments roughly obey the magnetic Bode's law. We assumed a 1 - 5% conversion efficiency, $\dot{W}_E = 5 \times 10^{11}$ W, and that the bandwidth is roughly half the peak frequency, which is assumed to scale as the surface magnetic field. In figure 2 we plot the peak power flux for 1 and 5% efficiency for Uranus, Neptune, Saturn and Jupiter, assuming various values of B_p. The Bode's law estimates are indicated by a cross. We have superposed

curves of earth interference at 30 R_E and galactic noise.

It appears that MRB from Uranus and Neptune might well be detectable from earth, especially if their magnetic fields turn out to be smaller than the Bode's law estimate. Figure 2 also indicates that the situation only improves away from earth, since the earth continuum noise is reduced and the power fluxes from Uranus and Neptune should increase as the square of the distance to the planet. We therefore suggest that detection of magnetospheric radio bursts from Uranus and Neptune might be a reasonable cruise mode radio astronomy objective on future missions to the outer solar system.

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FIGURE CAPTIONS

Figure 1. The observed power flux spectra of very intense radio bursts from earth (Gurnett[2]), Jupiter and Saturn (Brown[3,5]) are plotted normalized to the solar wind energy input into the magnetosphere of each planet as a function of frequency normalized to the electron gyrofrequency near the surface magnetic pole. The magnetic fields of earth and Jupiter have been measured, Saturn's field is predicted by using the magnetic Bode's law. All spectra peak between 10 - 20% of the surface electron gyrofrequency and have similar bandwidths, but Jupiter and Saturn produce more power relative to the solar wind input than does the earth. This implies that either Jupiter and Saturn are more efficient or that the power source for MRB from Jupiter and Saturn may not be the solar wind. For completeness we have also sketched a spectrum based on properties of EMRB described by Kaiser and Stone[1], whose experiment had many more channels in the frequency range of interest than did Gurnett's[2], but not enough dynamic range to measure the most intense EMRB. The total power radiated in MRB relative to the solar wind input can be obtained directly from this plot by taking the peak of the normalized power spectrum and multiplying by the bandwidth measured in normalized frequency. We assumed that $\dot{W}_E \sim 5 \times 10^{11}$ W, because, according to the solar wind scaling hypothesis, the most intense MRB should correspond to an intense solar wind.

Figure 2. The locus of the peak in the MRB power flux spectrum at earth is shown as a function of surface magnetic field strength for efficiencies of 1 and 5% for conversion of solar wind power input into the planet's magnetosphere to the most intense MRB. The surface field strength ranges from .1 to 10 times the magnetic Bode's law value, which is indicated by a cross for each planet. The peak frequency is assumed to vary linearly with surface field strength, B_p. The bandwidth of MRB is taken as half the peak frequency, and since the solar wind power input varies as $B_p^{2/3}$, the peak power varies as $B_p^{-1/3}$. The peak power flux of MRB from Uranus and Neptune is conjectured to lie between the 1 - 5% lines. The noise level of a short electric dipole in earth orbit at 30 R_E is indicated by the dash-dot line. Both Uranus and Neptune are near the noise levels, but MRB from both planets may be detectable from earth orbit, especially if the surface field strengths are below the magnetic Bode's law estimate.

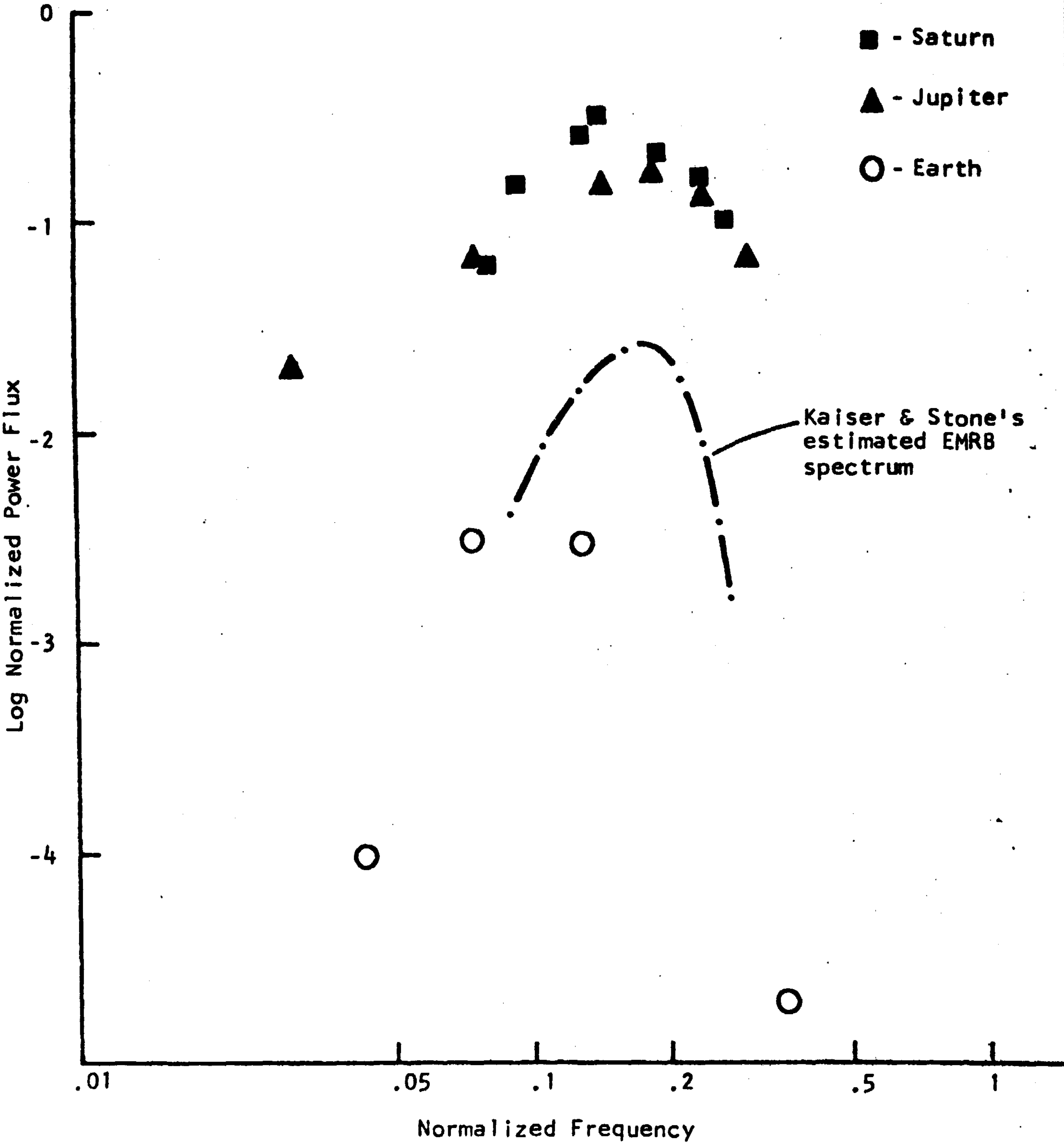

Figure 1

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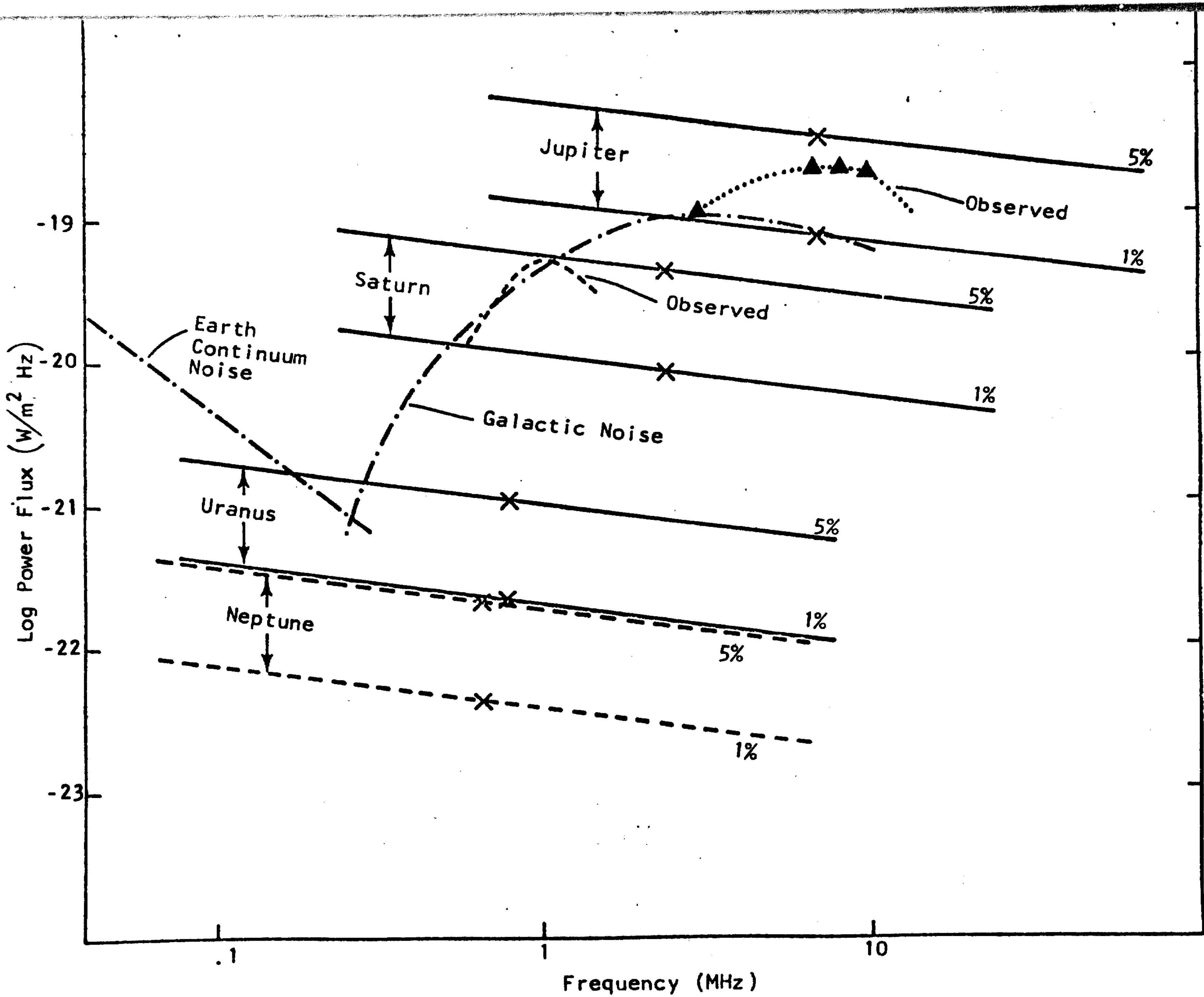

Jupiter
5%
Observed
1%
Saturn
5%
Observed
1%
Earth Continuum Noise
Galactic Noise
Uranus
5%
1%
Neptune
5%
1%
-19
-20
-21
-22
-23
Log Power Flux (W/m² Hz)
.1
1
10
Frequency (MHz)

Figure 2

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